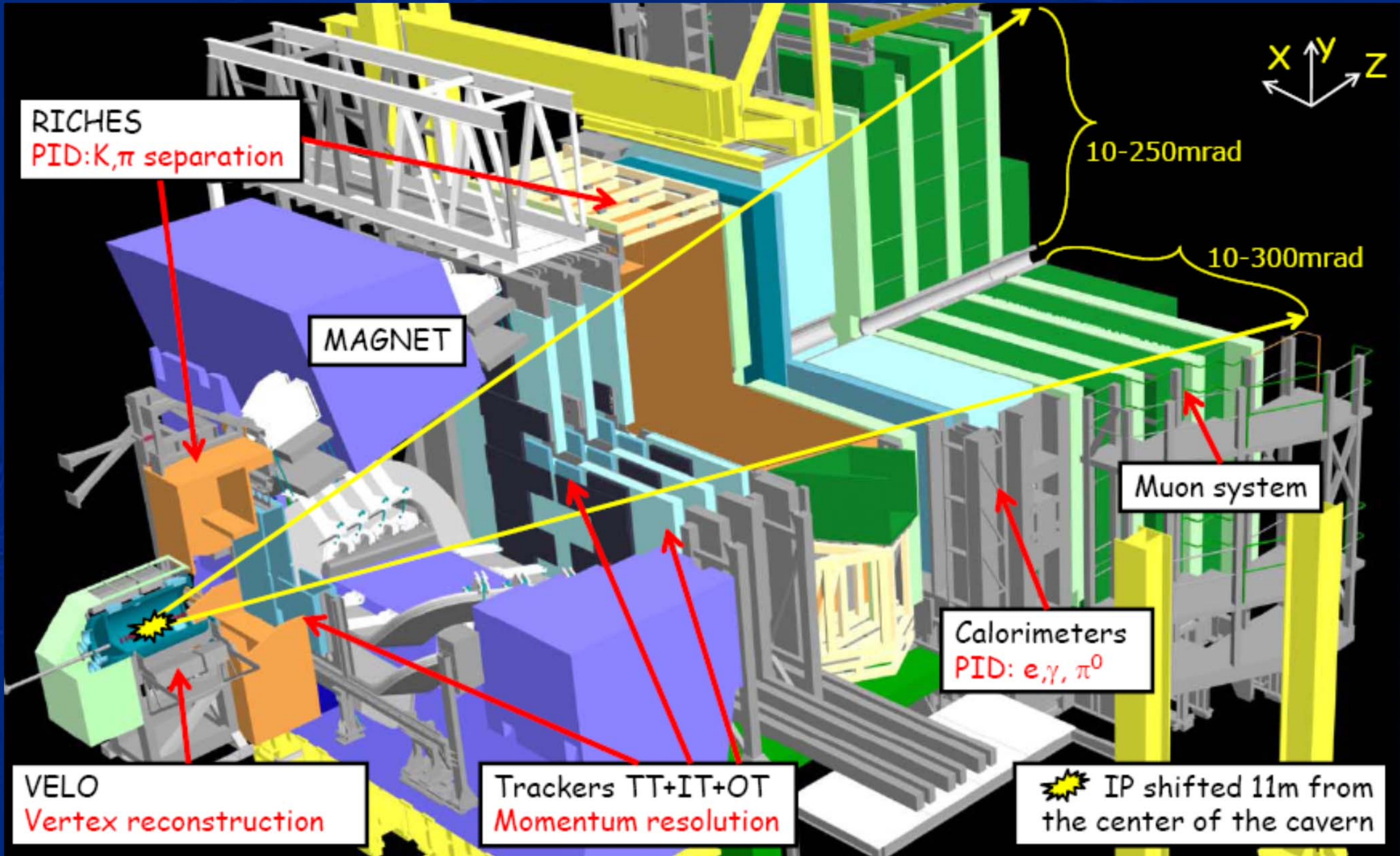
Operational Experience of the Triple-GEM Detectors of the LHCb Muon System: Summary of 2 years of data taking

Alessandro Cardini / INFN Cagliari, Italy
Giovanni Bencivenni / LNF INFN, Italy
Patrizia de Simone / LNF INFN, Italy

Outline

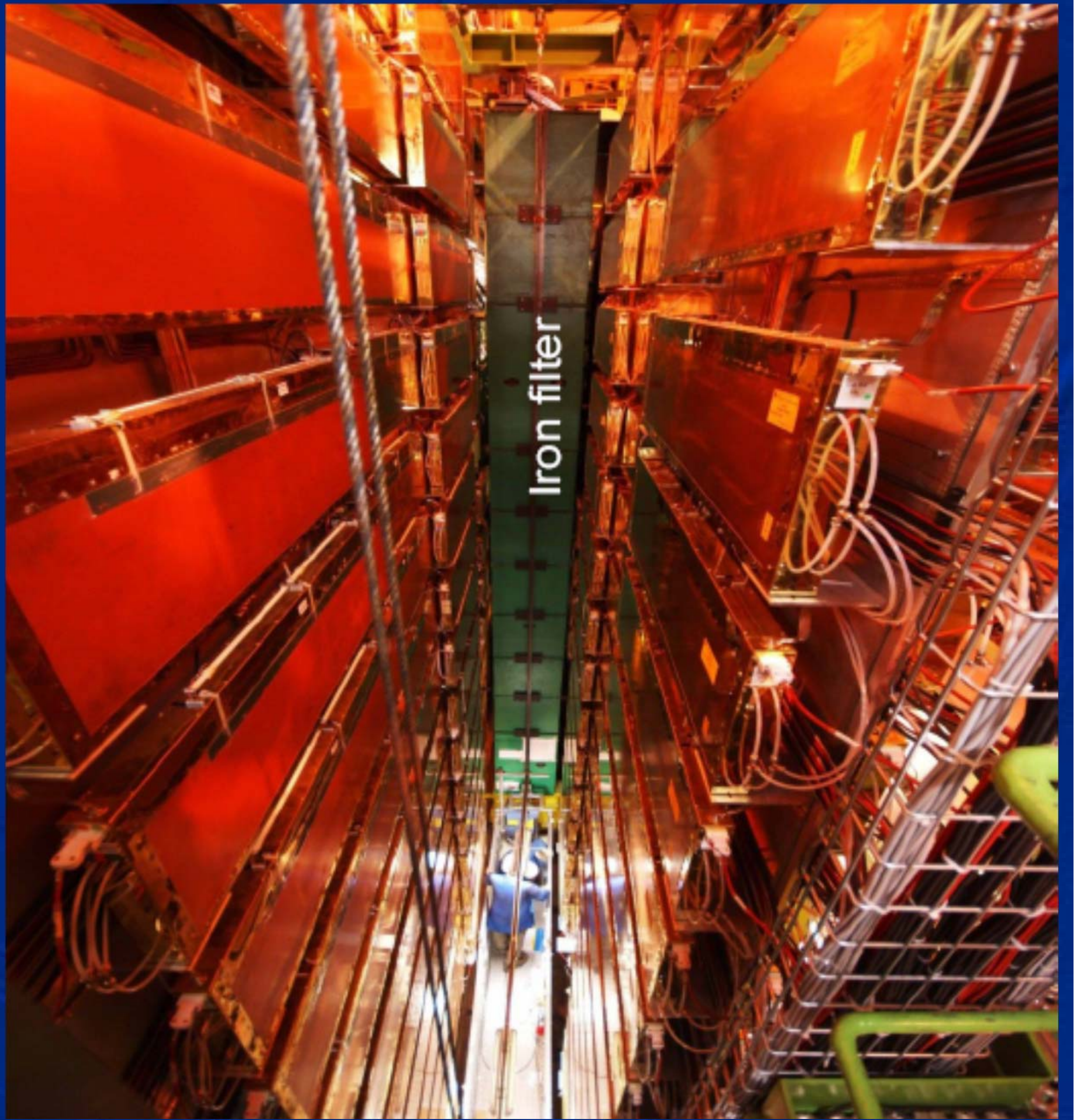
- The LHCb Experiment
- Designing Triple-GEM detectors for LHCb
- The Operational Experience
  - High Voltage optimization
  - Gas monitoring
  - Some other points
- Conclusions

The LHCb Experiment



The LHCb Muon System

- It provides:
  - hardware muon trigger (L0 muon)
  - muon(s) p_T estimate(s)
  - muon identification at the High Level software Trigger (HLT) and for offline event reconstruction
- 5 stations separated by Fe walls, projective geometry
- Mainly made of multi-wire proportional chambers
- First muon station (M1) located in front of the calorimeter
- M1 improves the p_t estimate at L0 trigger level
- In M1 central region (up to) 500 kHz/cm^2 ➔ triple GEM detectors
- M1R1: 0.6 m^2 ➔ 12 chambers of 20x24 cm^2 active area



LHCb Triple-GEM Detectors

Requirements: digital pad readout, up to 500 kHz/cm^2, 96% efficiency in 20ns time window, low cluster size (<1.2), no aging

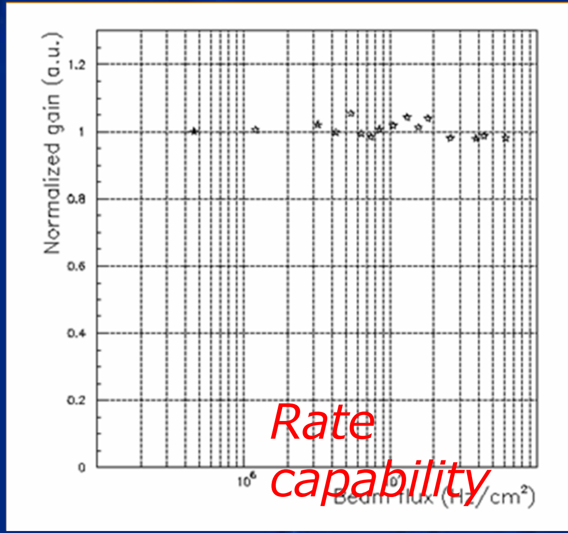
Non-standard gaps: 3mm (ioniz.) / 1mm / 2mm / 1mm (induct.)

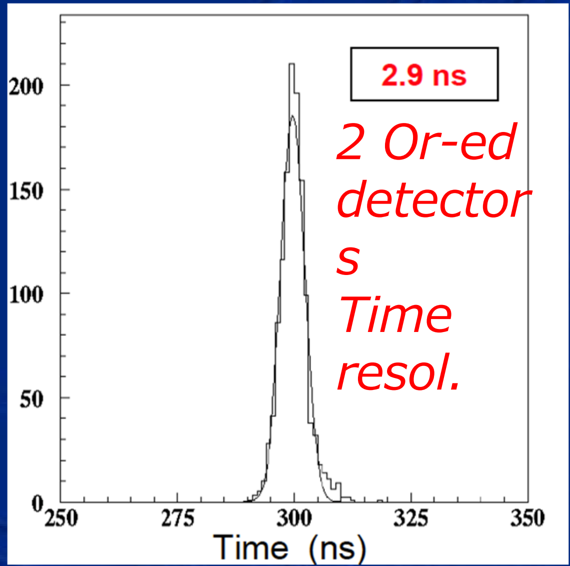
2 detectors in logical-OR pad-by-pad to improve performances & reliability

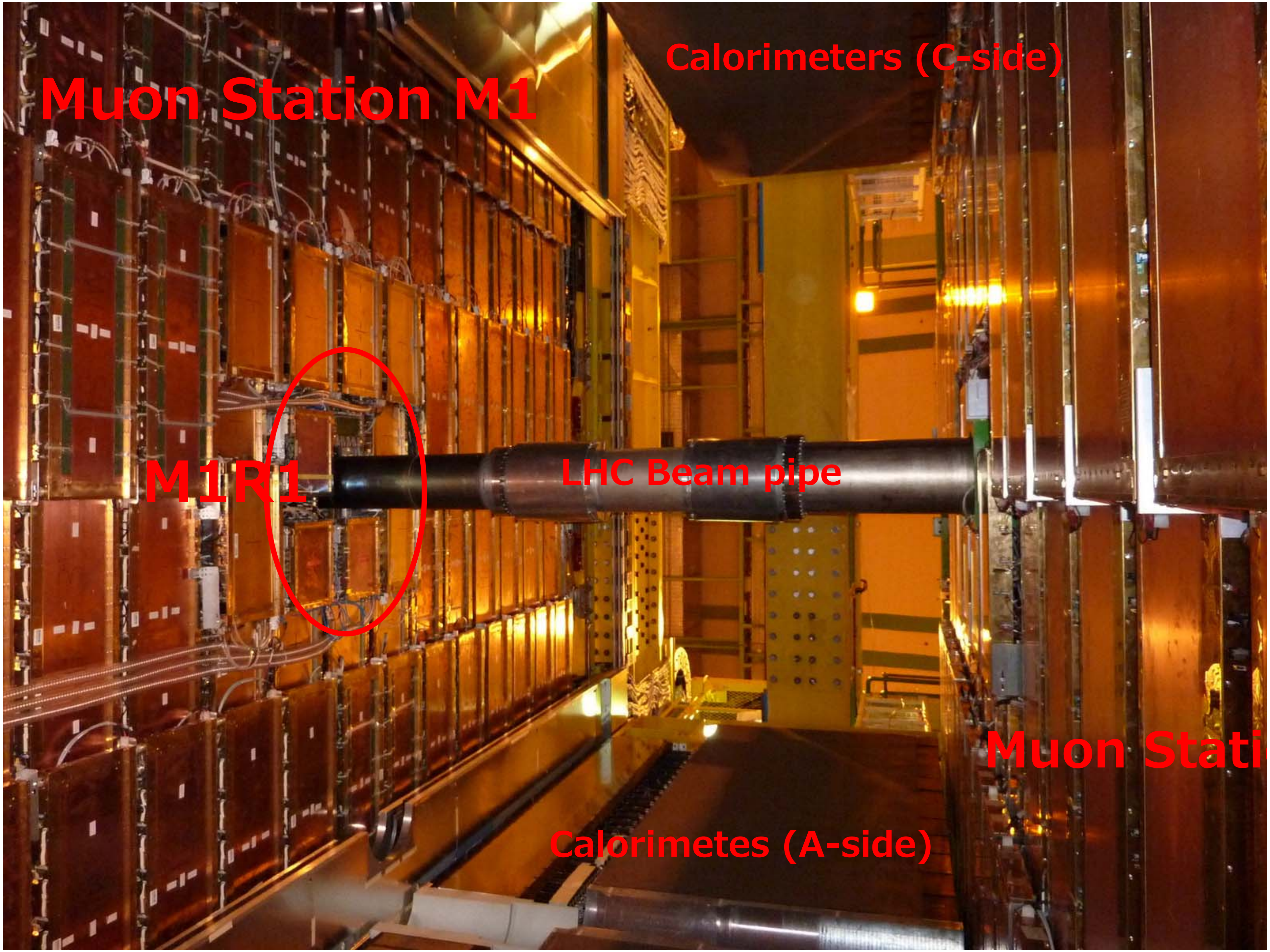
Innovative gas mixture: Ar/CO_2/CF_4 at 45/15/40

Wide working plateau: 70V

No aging effects seen up to 2.2 C/cm^2 during R&D






Muon Station M1
Calorimeters (C-side)
M1R1
LHC Beam pipe
Muon Stati
Calorimetes (A-side)


Zooming on M1R1...
M1R2 ch04
M1R2 ch06
CA-07
CA-02A

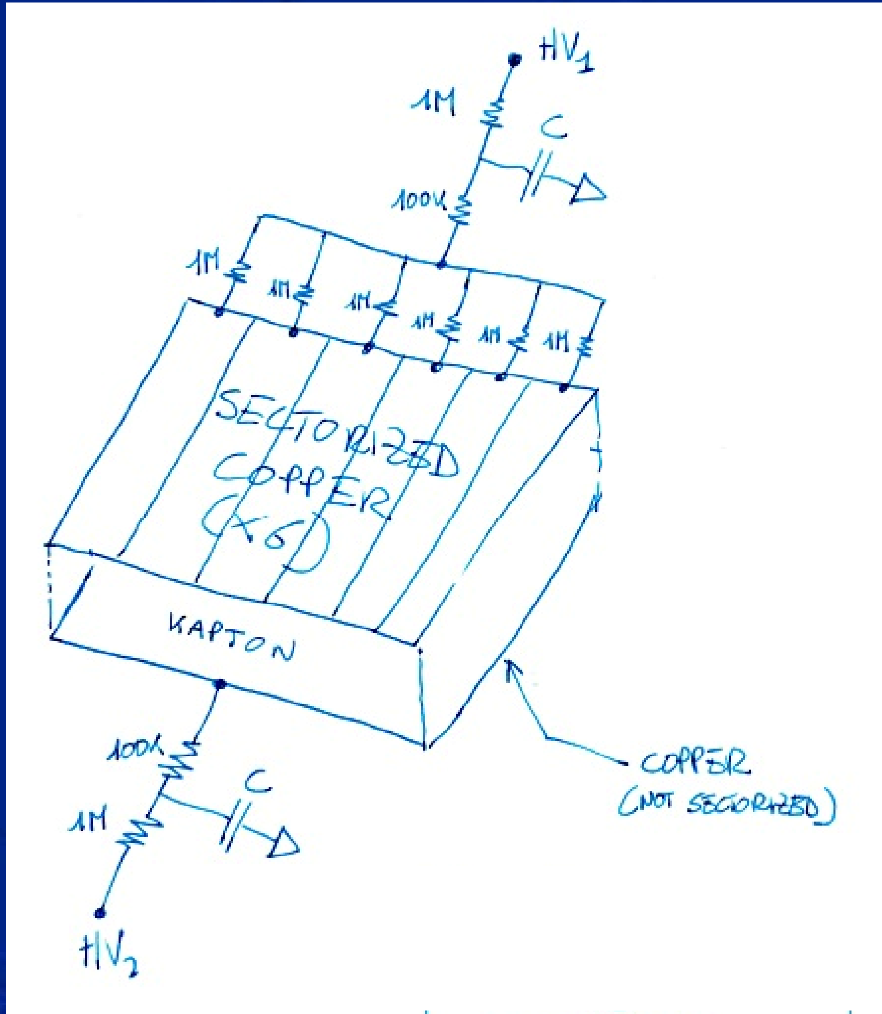
Operations in LHCb

HV-related issues:

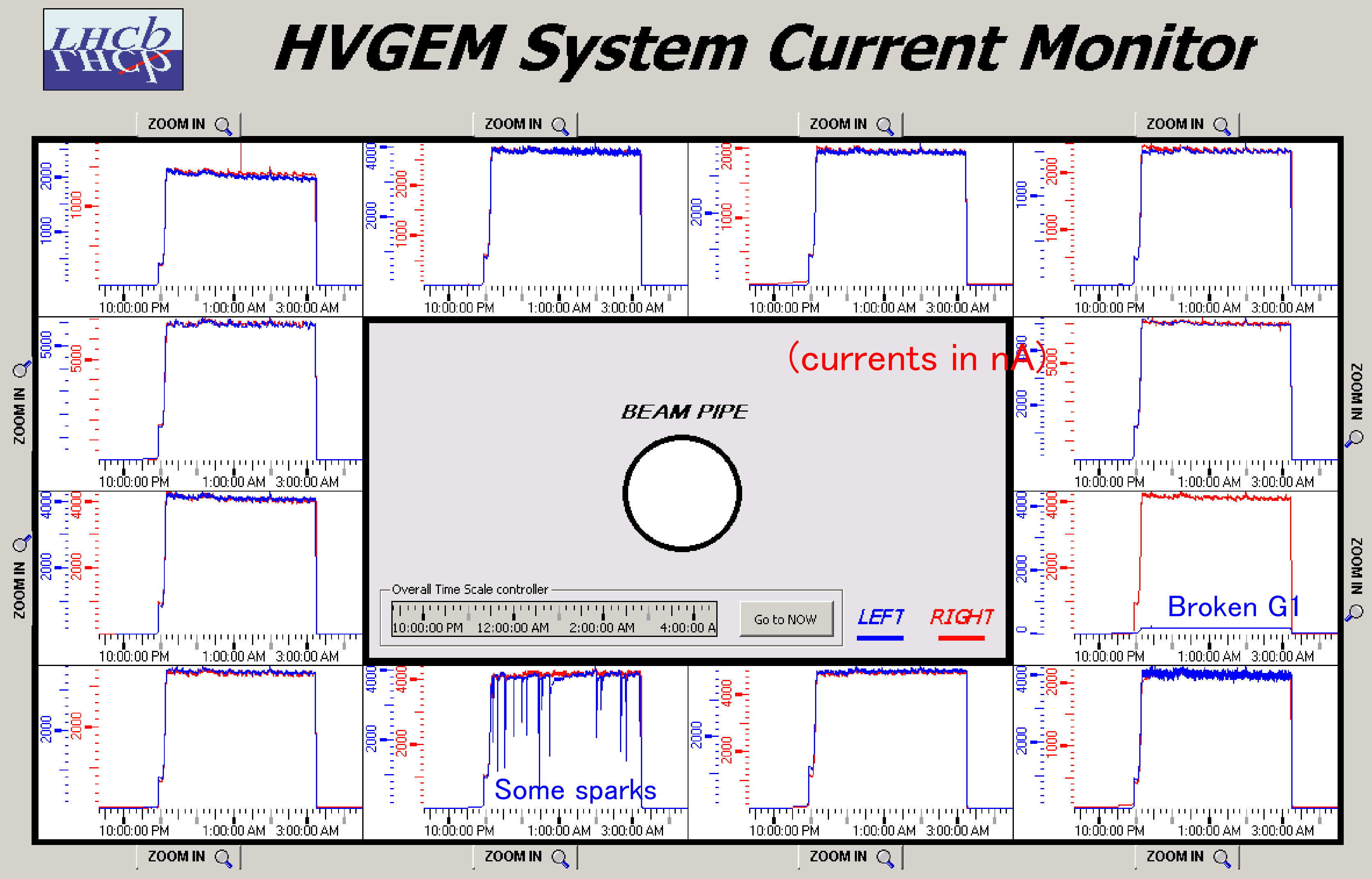
Tuning the detector working point

GEM Powering Circuit

- Custom-made multichannel HV power supply, electrically equivalent to an <u>active resistive divider</u>
- Detector current measured only on last GEM foil – all data logged by ECS
- Protection resistors on HV filters on detector + 1 MΩ in series on sectors for each GEM foil



Fill 3182, <L> = 3.96 $10^{32}/cm^2/s^{-1}$, 5.62 pb^{-1}, $4^h15'$



Sparks and Shorts

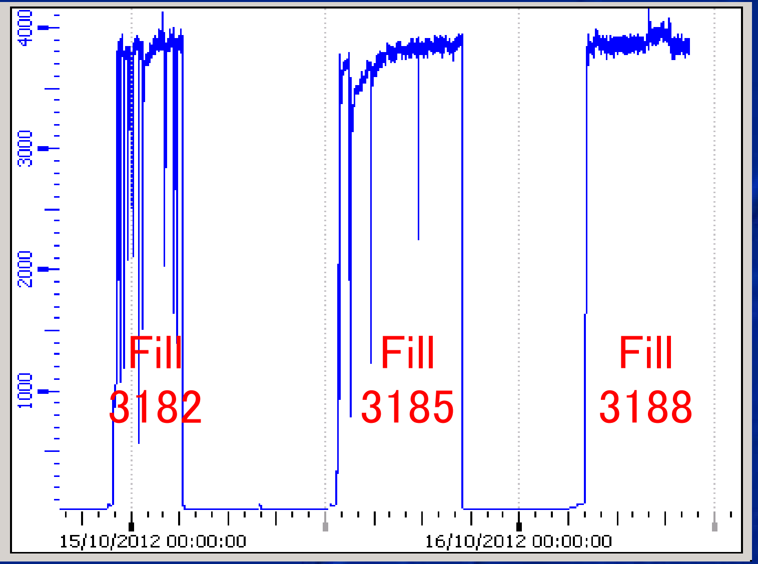
- Nowadays, LHCb Triple-GEM detectors are probably the ones running in the most severe conditions ➔ operating point is very critical

- Sparking events are detected by current monitor (not detecting which GEM foil is sparking)

- (Continuous) sparking could eventually result in a GEM foil short ➔ we need to minimize discharge probability in normal operations

- In these years of data taking we had some GEM in short, 1/2/1 respectively in 2010/2011/2012

- All these shorts occurred on first GEM (G1), the first amplification stage… Why?



Detector A15A1L current vs. time ➔ Sparking recovered by itself in this particular case

Tuning the HV Working Point

- Initial working point defined during R&D:
  - G_{min} ~ 4000 (min. required efficiency)
  - G_{max} ~ 17000 (PSI discharge probability measurements)

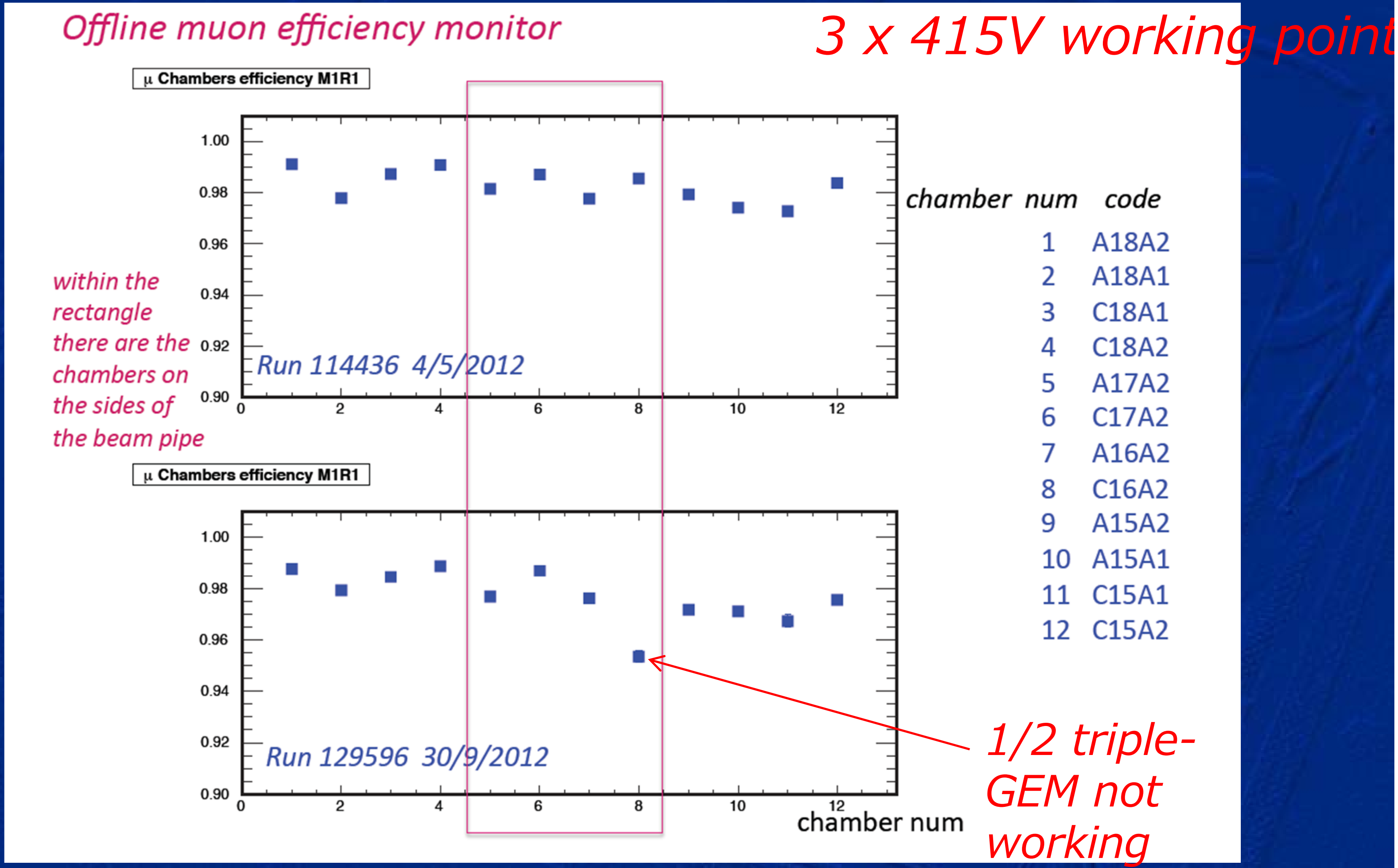
- "Traditional" considerations on Raether limit and laboratory measurements with alphas suggested GEM gains decreasing from GEM1 to GEM3

- April 2010: G~6000 (435V/425V/415V)

- Readjusted to lower gain values during 2010 and 2011

- May 2012: *go symmetric*! → 3x415V, safer for GEM1, G~4300

Detector performances in 2012



What we learned on HV

- Gain fine tuning needed because we observed
  - Sparking
  - Detector current instabilities

- It seems that in LHCb
  - Sparking rate is higher than expected: neutrons background
  - Low Z material of the detector: neutron converter ➔ HIP ➔ discharges
  - GEM1: Usually at a higher voltage ➔ more sensitive to discharges

- Solutions
  1. Reduce the gain – done
  2. Put all 3 GEMs at the same voltage – done
  3. Reduce the total voltage on GEMs and keep same gain by slightly changing the gas mixture (reducing CF_4 and/or adding isobutane) – proposed, under evaluation

Operations in LHCb

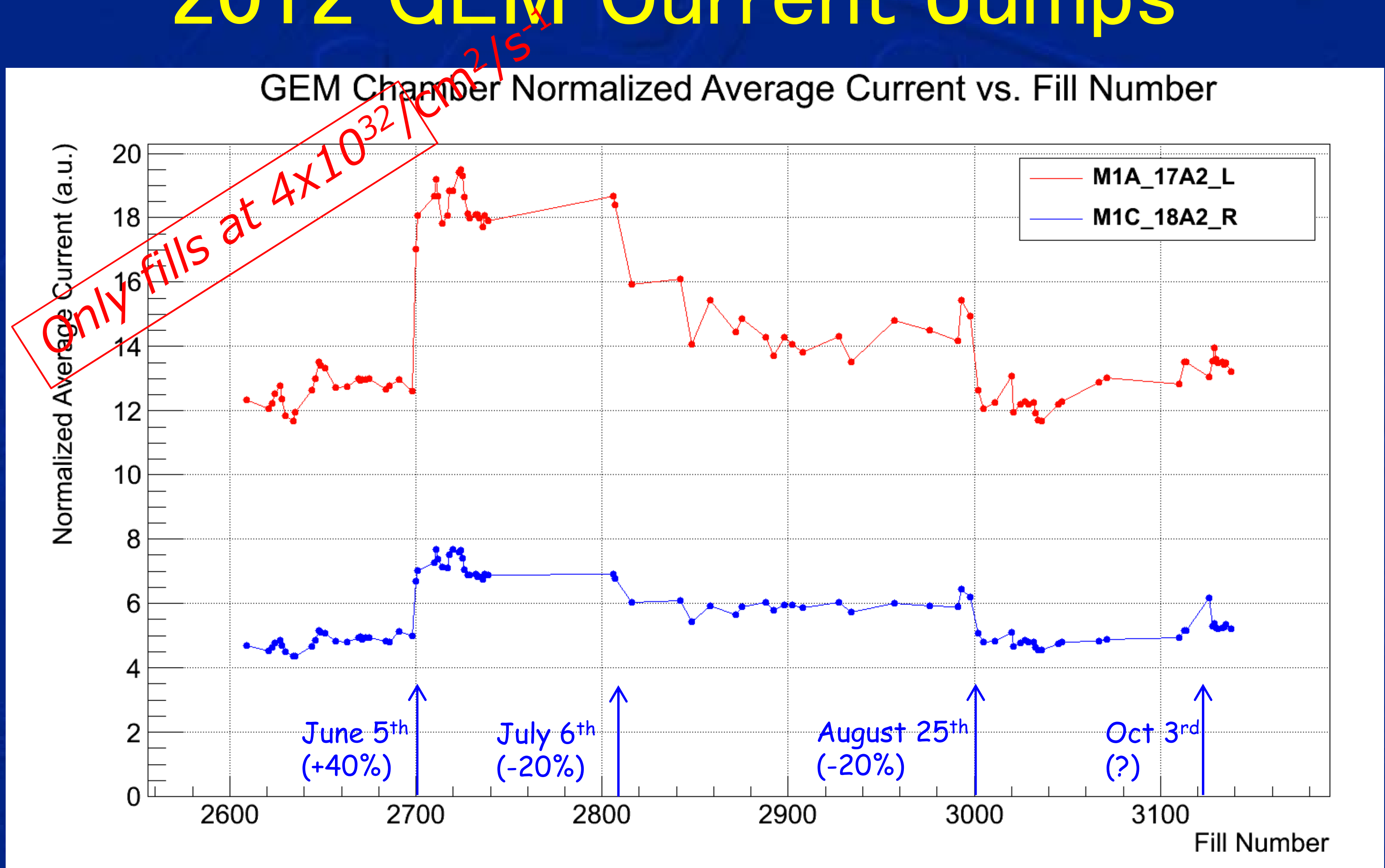
Gas-related issues:

Monitoring the Gas Mixture

The LHCb GEM Gas System

- Made by CERN Gas Group – Open-loop system
- $Ar/CO_2/CF_4$ in percentages 45/15/40
- Flows: ~80 cc/min per detector – monitored by ECS
- Fresh mix analysis permanent tools:
  - Gas Chromatographer (GC)
  - $H_2O + O_2$ measurement
- Possibility of sampling return gas with portable GC

2012 GEM Current Jumps

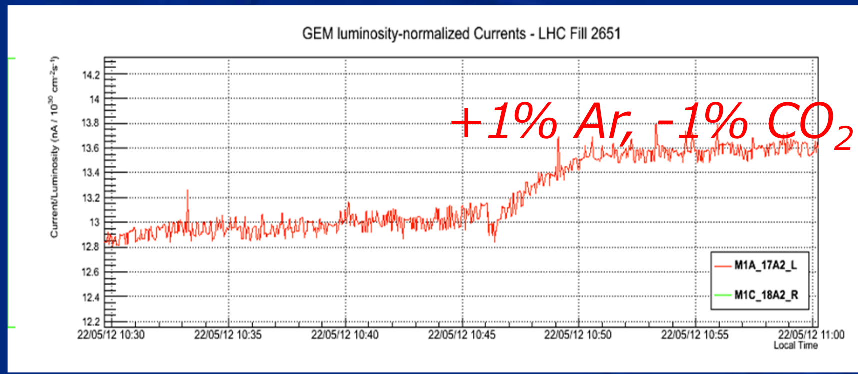


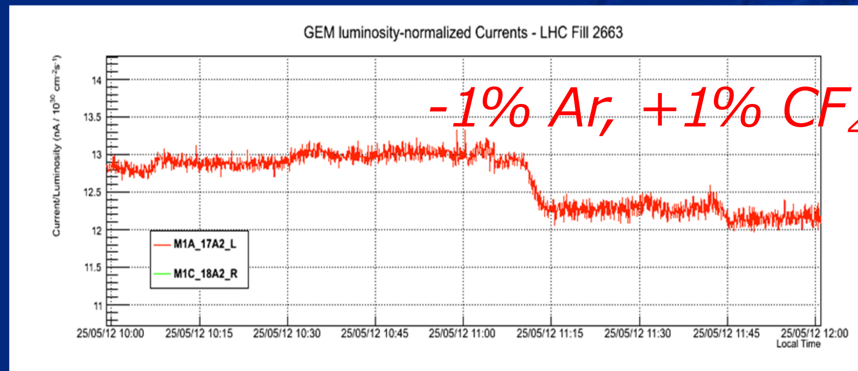
- Observed some “jumps” in ALL triple-GEM detector luminosity-normalized currents all along this year
- True Gain variations! ➔ detector signals move correspondently in time

Investigations performed

Possible causes of a gain change:

- Gas
  - GC-analysis show correct gas mixture within O(1%)
  - Small gas fraction changes (1%) create too-small gain changes (~5%)
- HV
  - 24 independent HV modules
- Temperature & Pressure
  - No temperature variations seen
  - Pressure variations not correlated

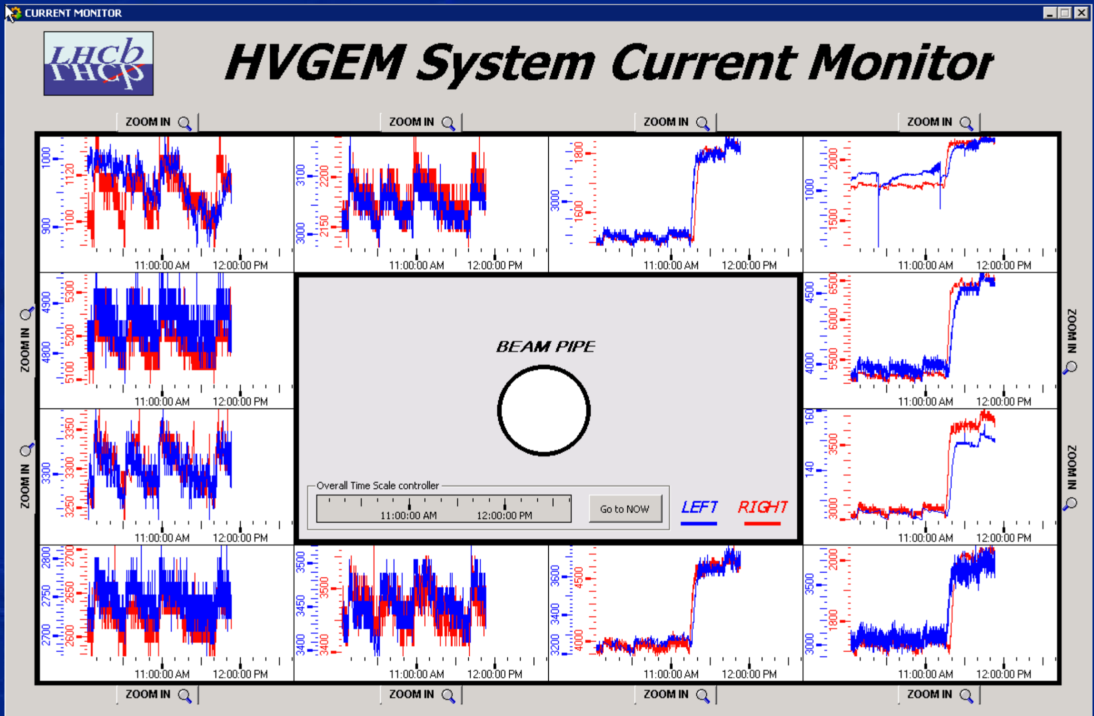




➔ *Origin of this problem???*

Premixed Gas Test

- Inject gas from pre-mixed bottle only on half of the detectors



- Should be the same gas… *but 20% current increase observed!*

➔ It's definitely something related to gas…

At last…

- Some correlations were found by Gas Group (R. Guida, B. Mandelli et al., see poster N14-132)
- It appears that some of the gain jumps are in coincidence with the change over of the CF_4 bottles
- Looking carefully at GC analysis some variations of O_2/N_2 seen… is this correlated?
- Situation not yet clear – will carefully monitor future CF_4 bottle changes

What we learned? What to improve?

- Gas mixture is a very critical point
- Gas monitoring units (GC, …) are excellent devices, but sometimes you do not know what to look for
- Imperative to implement redundant gas checking tools

1. Automatic current/luminosity checks – done
2. Independent gain monitoring tool with a small source-irradiated triple-GEM detector – in progress

Operations in LHCb

Other issues:

"Classical" aging

Integrated charges in 2012

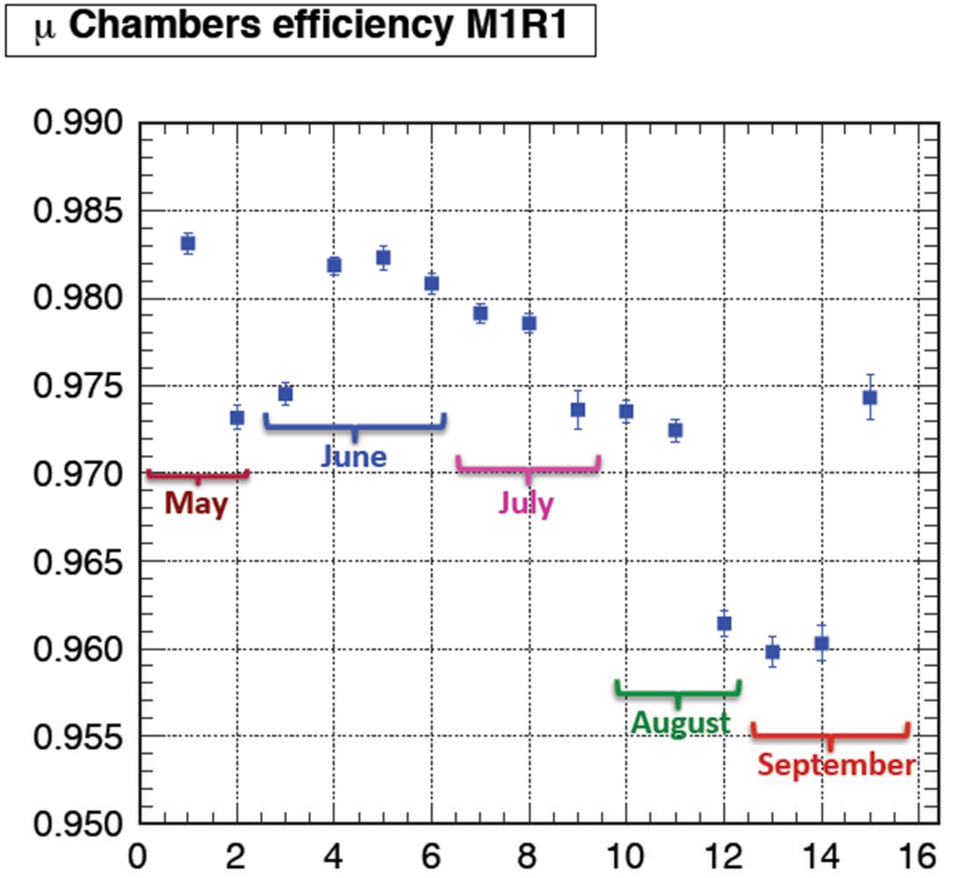
A18A2L: 18 mC/cm²	A18A1L: 34 mC/cm²	C18A1L: 31 mC/cm²	C18A2L: 13 mC/cm²
A18A2R: 12 mC/cm²	A18A1R: 23 mC/c[illegible]	C18A1R: 17	C18A2R: 21 mC/cm²
A17A2L: 50 mC/cm²	*Beam Pipe*		C17A2L: 42 mC/cm²
A17A2R: 59 mC/cm²			C17A2R: 60 mC/cm²
A16A2L: 35 mC/cm²			C16A2L: n/a
A16A2R: 35 mC/cm²			C16A2R: 35 mC/cm²
A15A2L: 30 mC/cm²	A15A1L: 33 mC/cm²	C15A1L: 33 mC/cm²	C15A2L: 34 mC/cm²
A15A2R: 29 mC/cm²	A15A1R: 36 mC/cm²	C15A1R: 41 mC/cm²	C15A2R: 18 mC/cm²

- E[illegible] 1 + 20[illegible]
- No indications of "classical" aging
- We expected twice this value→ Operating detector on the safe side!

Conclusions

Triple–GEM Efficiencies in 2012

Average Luminosity ~ 4 x 10^{32} /cm^2/s^{-1}



	fill	*run*
4/5	2587	114436
11/5	2609	115063
3/6	2692	117276
8/6	2712	117776
10/6	2718	118240
16/6	2734	118730
4/7	2806	120195
16/7	2843	121798
30/7	2892	124224
2/8	2902	124494
16/8	2976	125788
28/8	3011	126677
4/9	3025	127070
16/9	3067	128426
30/9	3113	129596

Excellent Performance Overall

- The LHCb GEM detectors are operating in very hard conditions (high irradiation, long runs)

- A few shorts on G1 occurred during these years of data taking → tune working point → situation improved

- Effect of *heavy ionizing particle* has to be taken seriously into account in a hadron collider environment

- Monitoring and debugging tools are never enough

Backup slides

Why Triple-GEM were chosen

- The requirements for detectors for the inner region (R1) of the first muon station (M1) (~0.6m^2 but ~25% of the muon acceptance) are:

  - Rate Capability up to 0.5 MHz/cm^2
  - Station Efficiency 96% in a 20 ns time window (*)
  - Cluster Size 1.2 for a 10x25 mm^2 pad size
  - Radiation Hardness 1.6 C/cm^2 in 10 years (**)
  - Detectors active area 20x24 cm^2

  (*) A station is made of two detectors "in OR". This improves time resolution and provides some redundancy

  (**) Estimated with 50 e$^-$/particle at 184 kHz/cm^2 with a gain of ~ 6000

- With a long R&D work (2000-2003) we demonstrated that Triple-GEM detectors are an adequate solution for the M1R1 region

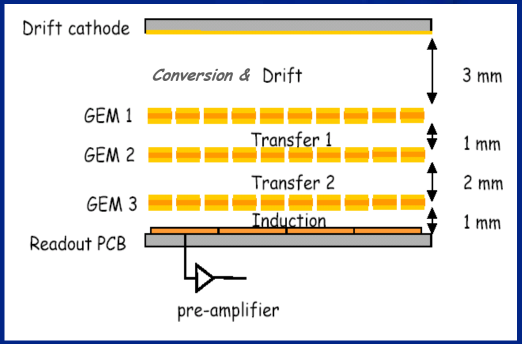
Triple-GEM Design and Optimization

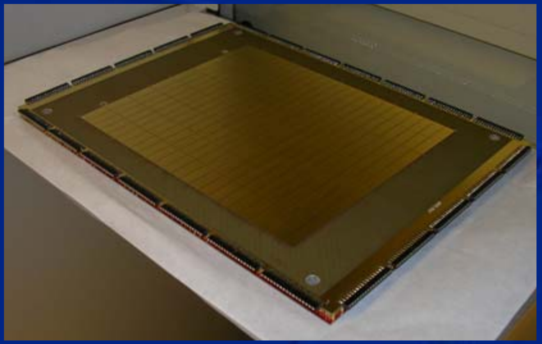
- Triple-GEM detector with anode pad readout – preamplifier and discriminator (CARIOCAGEM)

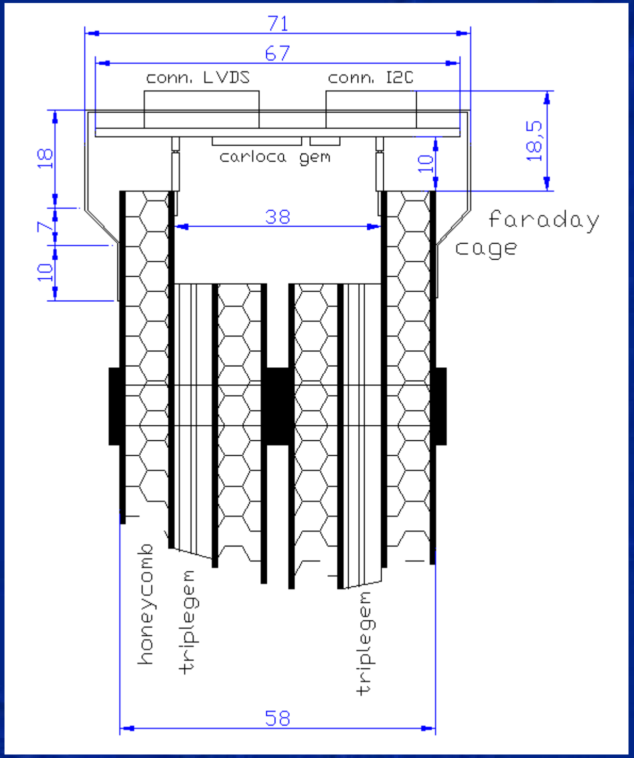
- Non-standard gaps
  - T1 is 1 mm to decrease the probability that a ionization in T1 could trigger the discriminator ➔ hits in advance ➔ worsening of time resolution
  - Induction gas is 1mm to have fast signals

- Standard CERN GEMs, 200x240 mm^2 active area, 6 sectors

- Full chamber is made by two detectors in OR pad-by-pad, via the front-end electronic board ➔ more redundant detector



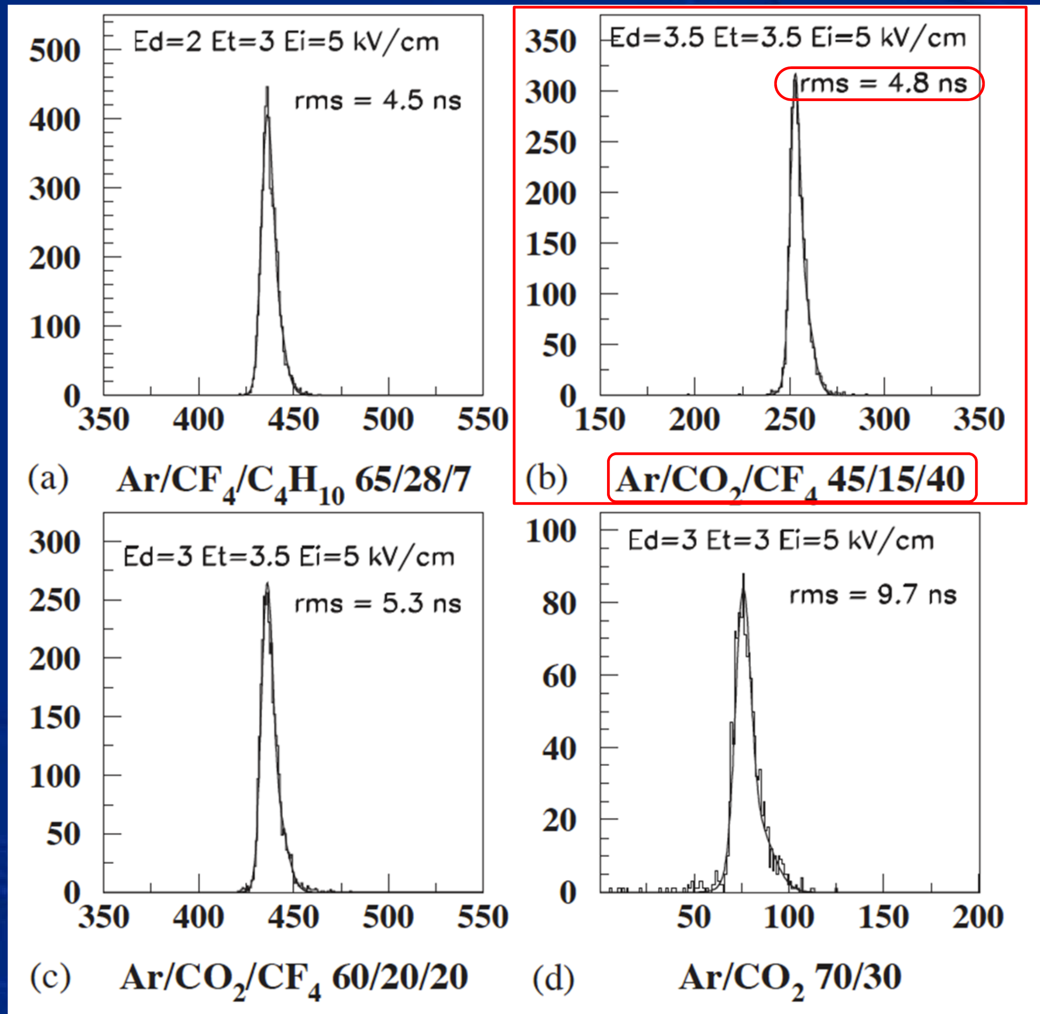




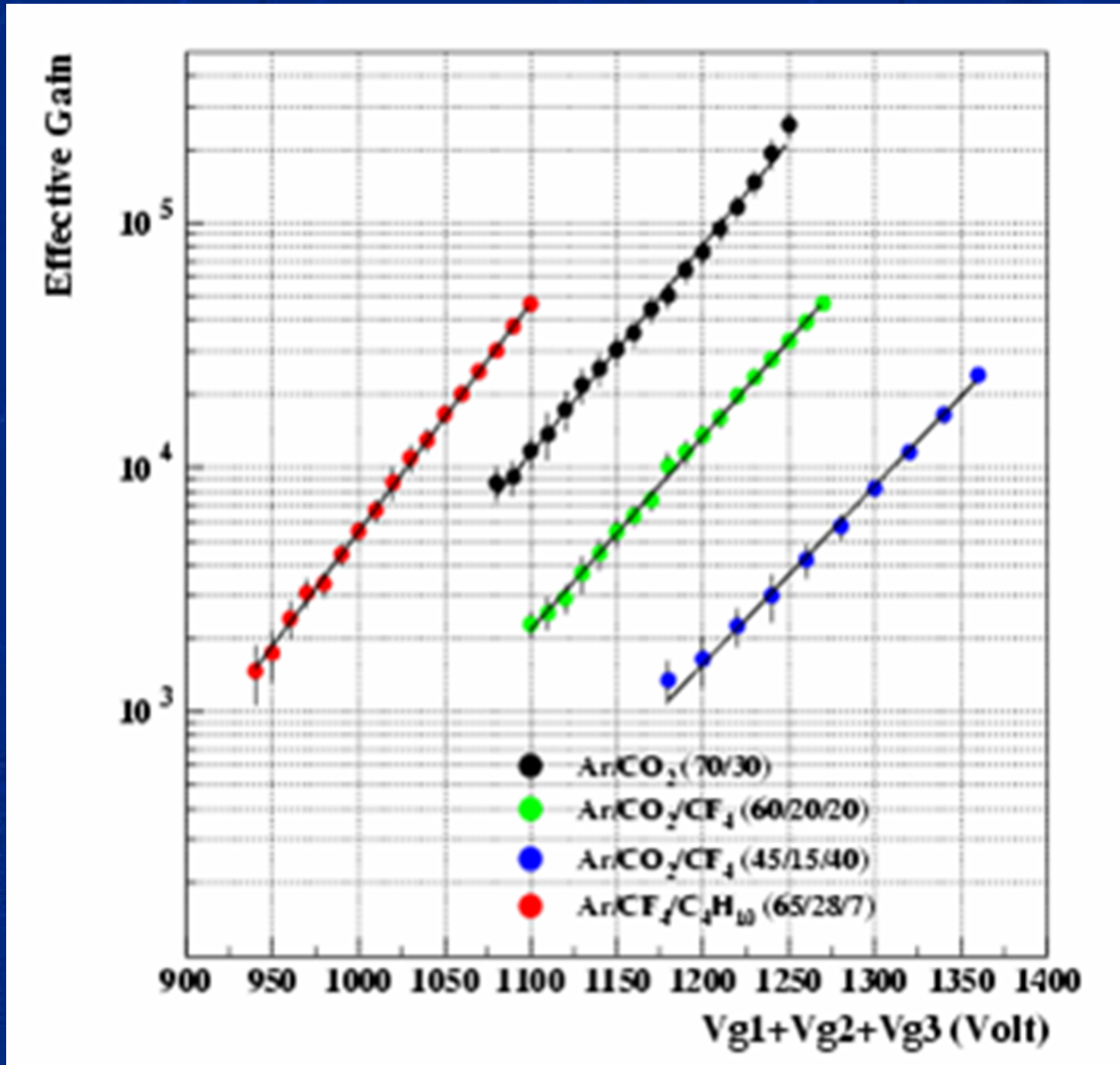
Gas Choice

- Fast and non-flammable gas
- CF_4 represent 40% of the mixture
- Requires a slightly higher voltage on GEM foils than a more classical Ar/CO_2 70/30 mixture

Triple-GEM Detector Time Resp

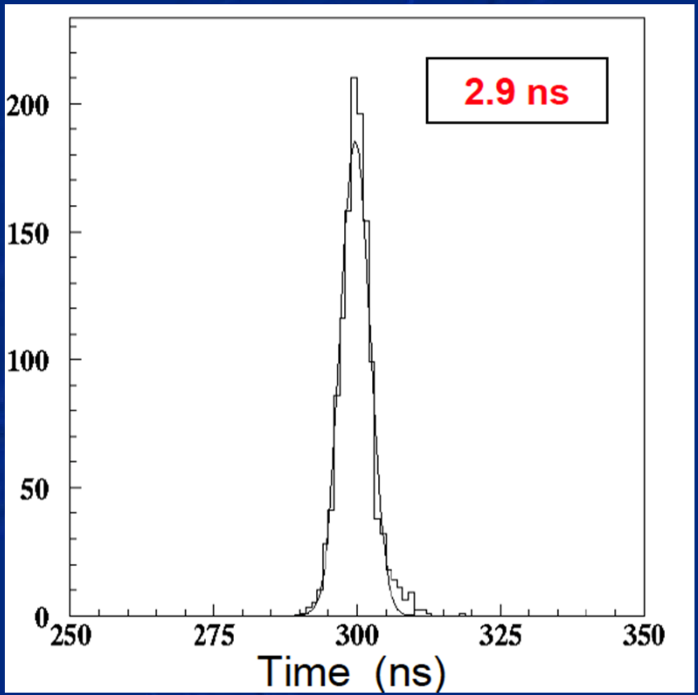


Gas Gain

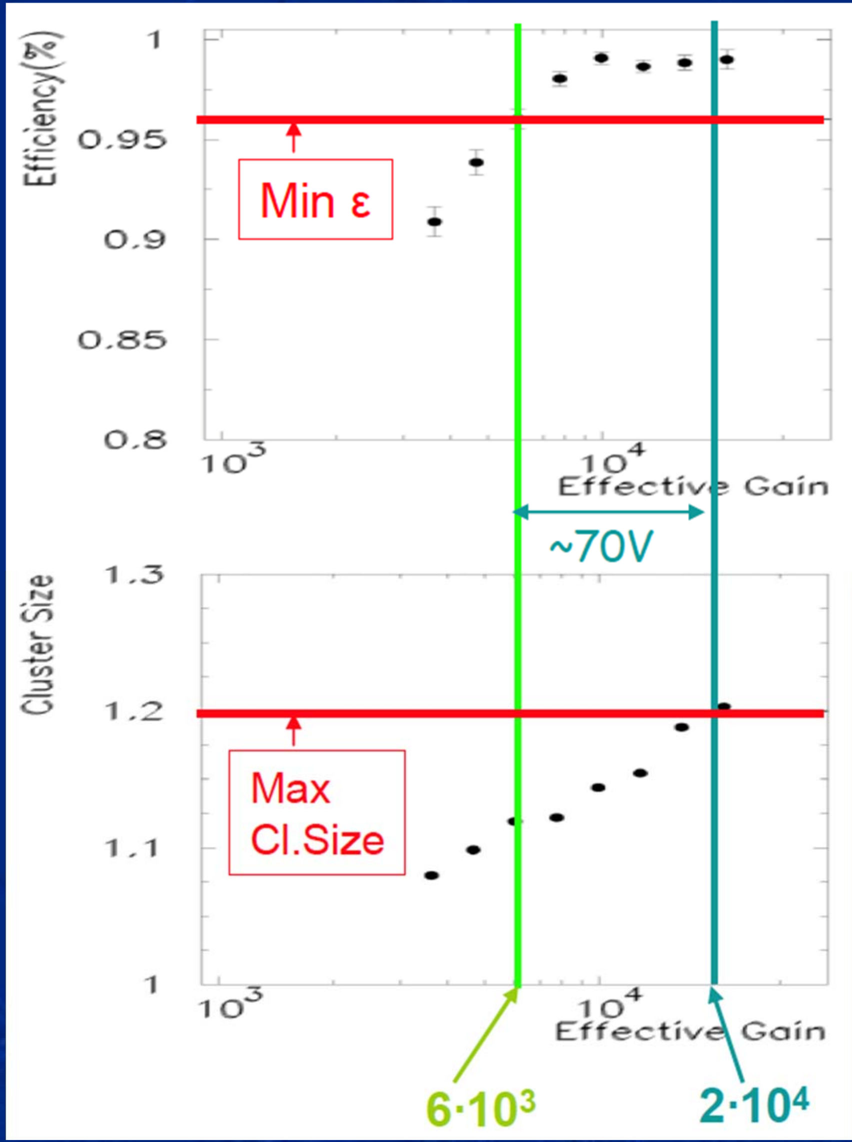


Effective Gain
10^5
10^4
10^3
Ar/CO_2 (70/30)
Ar/CO_2/CF_4 (60/20/20)
Ar/CO_2/CF_4 (45/15/40)
Ar/CF_4/C_4H_{10} (65/28/7)
900 950 1000 1050 1100 1150 1200 1250 1300 1350 1400
Vg1+Vg2+Vg3 (Volt)

Full Chamber Performance

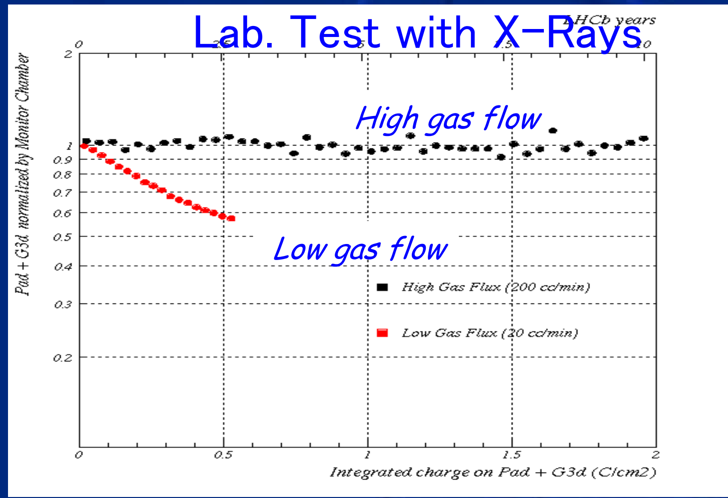


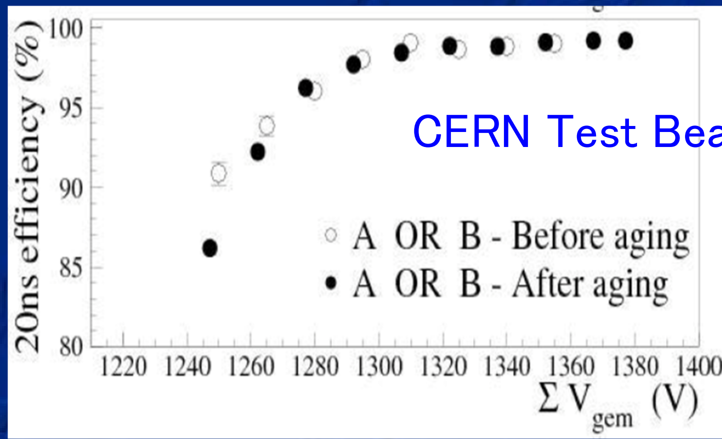
- Excellent time resolution with 2 detectors in OR
- Wide HV operating plateau



Ageing Tests during R&D

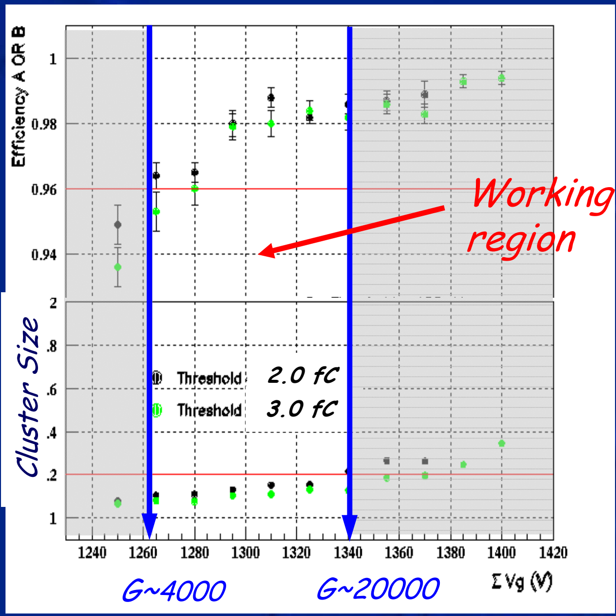
- Many aging tests performed, exceeding expected LHCb integrated charge
  - Local: 6 keV X-Rays, ~1 cm^2
  - Large Area: PSI πM1 hadron beam, ~15 cm^2
  - Full detector: Enea-Casaccia 25 kCi ^{60}Co source, 0.5 ÷ 16 Gray/h
- For all tests except high-rate Casaccia, no ageing was observed
- High-rate Casaccia tests showed a gain reduction effects, found to depend on a low gas flow to irradiation ratio
- All ageing effect, if present, can be compensated by readjusting the detector HV

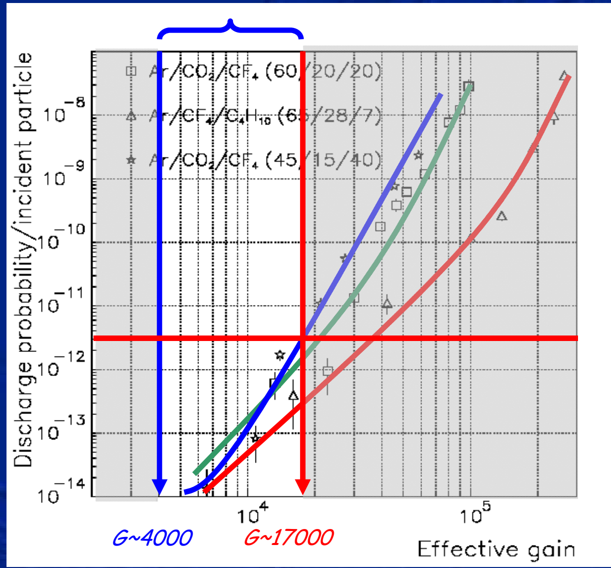




Tuning the HV Working Point

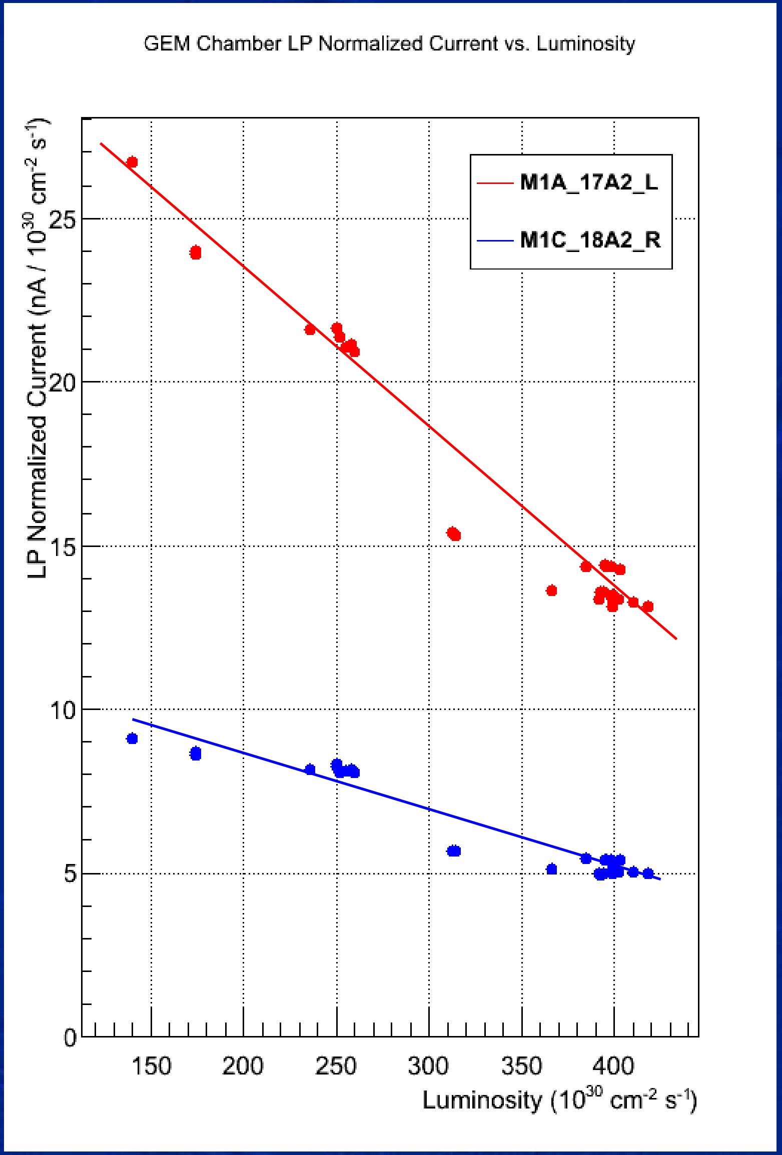
- Working point defined during R&D work
- "Traditional" considerations on Raether limit suggested a gain decreasing from G1 to G3
- April 2010: 435V/425V/415V, G~6000
- October 2010: Some instabilities observed ➔ Tested some reduced configurations: 430V/420V/410V and 425V/415V/405V
- May 2011: Switched to more conservative 420V/415V/410V
- June 2011: Some instabilities on a few detectors ➔ 415V/415V/410V on these
- May 2012: *go symmetric*! ➔ 3x415V, more safe for G1, G~4300





High Luminosity and HV filters

- LHCb designed to run at average luminosity of $2x10^{32}/cm^2/s^{-1}$
- HV filter and protection resistors calculated to have a low (but unavoidable) voltage drop on GEM foils
- Now running routinely $4x10^{32}/cm^2/s^{-1}$ ➔ gain depends on instantaneous luminosity
- Planning to redesign these HV filters, to be replaced during LS1



Detector Gain Monitoring

- 10x10 cm^2 triple-GEM detector
- ^{90}Sr source ➔ monitor detector current
- Possibility of using fresh or return gas, or gas from premixed bottle (reference)
- Working but not in normal operation
- Will be completed and integrated in LHCb ECS during LS1